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16. Abstract (MAXIMUM 200 WORDS)

This is a report on the development of a Life Cycle Cost (LCC) model that compares costs for traditional propulsion systems to costs of marine propulsion systems that incorporate fuel cells. The Coast Guard is interested in applying fuel cell technology for shipboard applications where high efficiency and reduced pollution are critical. Similar cost comparisons are also made for ship service generators. The program sums acquisition costs of the machinery system of a vessel, the operational costs including fuel and maintenance, manning costs and disposal costs. An allowance for exhaust emission credits/penalties is included in the program. The description of the program and of all the major assumptions leading to the present and future cost figures is provided in this report. The Excel software used for this study is available from the technical point of contact listed above. A comparison of Life Cycle Costs for four marine propulsion systems is presented. A conventional diesel only system (CODAD) was compared to an Integrated Diesel Electric system (IDE) and then to the new powering systems, i.e., the Molten Carbonate (MC) and the Proton Exchange Membrane (PEM) fuel cell systems. The fuel cell models contained in this report are preliminary, as no historical shipboard data are yet available. Nonetheless, best estimates have been made, and all key variables can be altered to investigate sensitivity. This LCC model is expected to be refined as more accurate data, particularly with respect to fuel cells, becomes available.

17. Key Words
Life Cycle Cost (LCC), fuel cells, marine propulsion, Molten Carbonate Fuel Cell (MCFC), Proton Exchange Membrane Fuel Cell (PEMFC), Combined Diesel and Diesel (CODAD), Integrated Diesel Electric (IDE), net present value (NPV)

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EXECUTIVE SUMMARY

Fuel cells offer the potential for substantially better fuel efficiency and cleaner emissions than marine diesels or gas turbines. However, the greatest technical barrier to their shipboard use remains the difficulty in extracting the hydrogen for the fuel cell from the marine diesel fuel. Together, the U.S. Navy and the Coast Guard (USCG) have been working to develop systems capable of purifying and reforming diesel fuel for use in marine fuel cells. As these technical barriers are overcome, costs are expected to decrease with mass production and economies of scale. The USCG has previously completed a Market Survey Report (September 1999) which showed that there is significant potential for a marine market for such fuel cells, providing that total life cycle costs (LCC) can be made competitive with traditional sources of marine power.

This study provides a tool to compare the total life cycle costs of various types of ship powering and electrical generator systems on a consistent basis. Each system includes the basic power plant, and all required auxiliaries (e.g., fuel treatment, intake and exhaust systems, cooling, etc.). Acquisition costs include basic hardware, foundations, fabrication and shipboard installation. Recurring costs include fuel, lubricants, manning and maintenance. Emission penalties and disposal costs are also considered. Thus, the study enables total costs of competing powering systems to be estimated and directly compared. This capability is essential for conducting cost/benefit analyses, and to assess the economic competitiveness of shipboard fuel cell systems. This capability will benefit the Coast Guard in establishing a business case for further fuel cell R&D, and in developing commercial fuel cell systems for future use on Coast Guard cutters and other marine vessels.

The LCC program allows the selection of the following propulsion plant alternatives to be compared:

- Combined Diesel and Diesel (CODAD)
- Combined Diesel or Gas Turbine (CODOG)
- Combined Diesel and Gas turbine (CODAG)
- Combined Gas Turbine and Gas Turbine (COGAG)
- Integrated Diesel Electric (IDE) with Alternating or Direct Current (AC/DC) Motors
- Integrated Gas Turbine Electric (IGTE) with AC or DC Motors
- Proton Exchange Membrane Fuel Cell (PEMFC) with AC or Direct Current (DC) Motors
- Molten Carbonate Fuel Cell (MCFC) with AC or DC Motors.

Just as there is a choice of propulsion systems, the LCC program also allows the selection of the following alternative Ship Service Generators to be compared:

- Medium Speed Diesel or High Speed Diesel depending on industry practices in the power rating considered
- Gas Turbine
- MCFC
- PEMFC

The LCC program permits the user to specify speeds and durations within the mission profile. The comparison of each system includes calculations for acquisition and operational costs for all required auxiliary components (e.g., fuel, lube oil, cooling systems, reformers, fuel cell stacks, power conditioners, reduction gearing, propulsion motors, etc.)

The LCC model employs cost estimating relationships (CERs) based on the use of relationships between weights of equipment to be installed and the cost of the equipment and the installation activity required. The program contains a CER screen that shows the cost relationship for a propulsion system by ship work breakdown structure (SWBS). The screen shows the SWBS number, description of the SWBS category, weight of equipment, labor hours, material required (cost), labor rate, and total procurement cost for the SWBS category.

A standalone User's Manual is appended to this report (Appendix A). The program was validated for trends and for preliminary comparison between systems. Results of the comparison are provided in Appendix B. The actual software is written in Excel, and is available from Robert Sedat of the USCG R&D Center at (860) 441-2684, or e-mail: rsedat@rdc.uscg.mil.

A comparison of Life Cycle Costs for four marine propulsion systems is presented. A conventional Diesel only system (CODAD) was compared to an Integrated Diesel Electric system (IDE) and then to the new powering systems, i.e., the MC and the PEM fuel cell systems.

The initial cost of a 5475 kW integrated diesel-electric (IDE) system (including propulsion motors and installation) is $24,825,269, or $4534/kW. This compares to an initial cost of $36,118,681, or $6597/kW for a MCFC propulsion system. The annual operating costs of the MCFC system are lower than those of the IDE system. For the operational scenario studied, the annual fuel and lube oil cost savings with the MCFC system amount to $162,000 ($441,000 vs. $603,000) and a saving of $131,000 for maintenance ($794,000 vs. $925,000). This annual savings of almost $300,000 in operational costs is not sufficient to compensate for the difference in the initial costs. It is quite clear, however, that a change in fuel costs could make the fuel cell system economically feasible. If the diesel fuel cost were increased by a factor of 2.14 to $582/tonne (from current $272/tonne), roughly $1.93 per gallon, which is less than the cost of the diesel oil sold at gas stations in Europe, the net present value (NPV) of both systems, for the period of analysis, equalizes.

It must be admitted that certain parts of the LCC program require further verification before they can be used with confidence. In particular, all of the fuel cell costs, except fuel consumption and pollution reduction credits, lack service experience. It would also be useful to benchmark some of the diesel costs against installations that were not in the original database. Lacking definitive costs for maintenance (including fuel cell stack replacement), manning, and disposal, these costs are tentatively considered to be similar for both the fuel cell and the diesel electric powering systems discussed. The maintenance costs for fuel cell systems were modified to include the latest estimate of actual fuel stack replacement costs for replacement intervals of five years.

Emission penalties, once enacted and enforced, could add another $50,000 to the annual operating costs of a 5475 kW diesel propulsion system. This, by itself, may not be sufficient to equalize annualized costs, but added scrubbing requirements for the diesel electric system and increased fuel costs can do so.

The results presented here are subject to numerous assumptions, but give some idea of the comparative economics of a diesel electric system relative to a fuel-cell electric system. The fuel cell models contained in this report are preliminary, as no historical shipboard data are yet available. Nonetheless, best estimates have been made, and all key variables can be altered to investigate sensitivity. This LCC model provides a consistent tool to compare fuel cell economics to those of traditional marine powering systems.